Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft
Nuclear Facilities Decommissioning Division

Calculation of dose rate, decay heat and criticality for verifying compliance with transport limits for steel packages

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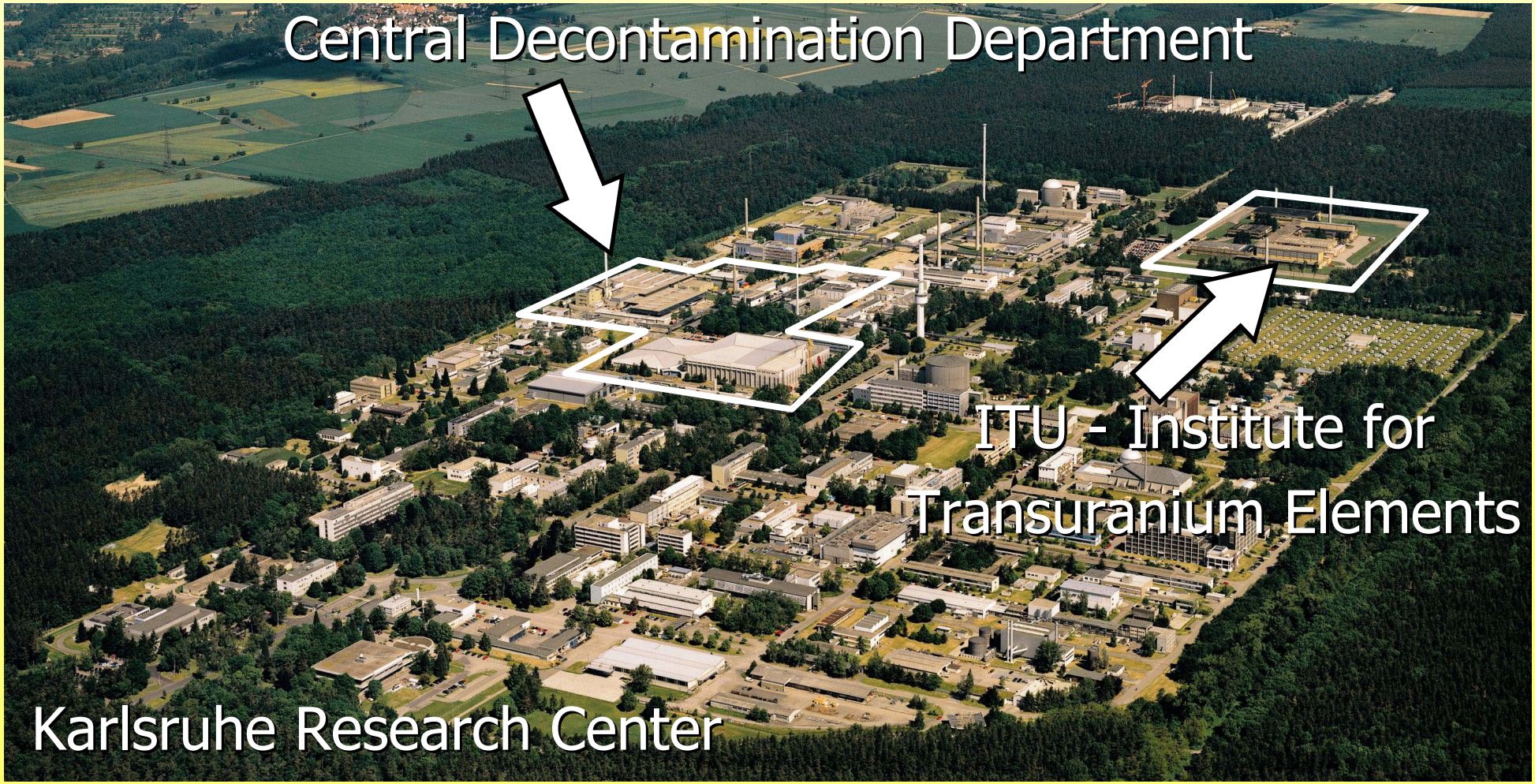
outline

- introduction: HDB
- motivation for calculations
- transport package
- nuclide inventory & calculation examples
  - application of Nuclides.net
- conclusion

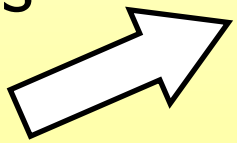
introduction: HDB

HDB - Hauptabteilung Dekontaminationsbetriebe



HDB activities

- safe utilization
  - decontamination
  - release measures
- infrastructure
  - entrance store
  - intermediate store
  - documentation
- conditioning of radioactive waste
  - incineration
  - evaporation
  - compaction
  - cementation



important information for transport

- declaration of nuclides
- activity

HDB facts

⇨ 60 % of the German 'Federal' nuclear waste

- from laboratories and decommissioned nuclear reactors
- from the Karlsruhe Reprocessing Plant WAK
- from the European Institute for Transuranium Elements (ITU)
- from various institutions and industries

⇨ Baden-Württemberg state collection center

⇨ **65000 drums in 5500 container**
⇨ **55000 m³ storage volume**

motivation for calculations

- transport of conditioned radioactive waste to
  - a nuclear waste repository
  - the originator

BUT

- declaration of nuclides
- safety considerations
  - dose rate
  - criticality
  - decay heat
- transport in EU regulated by ADR / RID 2005

NEED

⇨ **approved transport package**

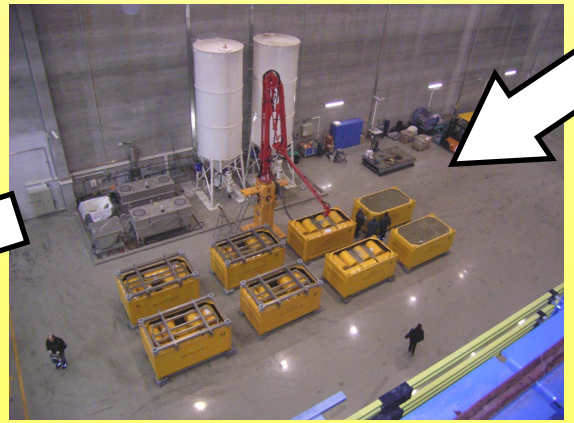
transport package

conditioned radioactive waste
– e.g. 200 l drums

- steel container
  - Typ IV (Konrad)
- volume approx. 7 m^3
- load max. 20 Mg

packaging of a steel container

- steel container contains (e.g.)
  - 14 drums with conditioned radioactive waste
  - mixed radioactive inventory
- activity max. 1 TBq
- encapsulation in inactive cement

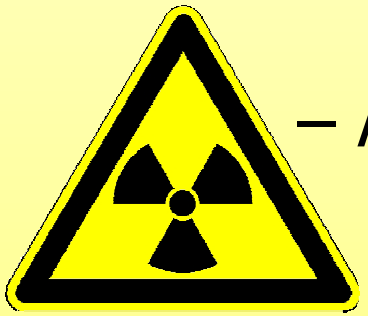


⇨ **conditioned radioactive waste within a transport package**

transport safety

- ⇨ required information
  - – activity
  - – criticality
  - – decay heat
  - – half-life

- ⇨ transport limits
  - – radiation protection ordinance
    - • HDB regulations (indirect)
    - • KONRAD regulations (indirect)
  - – ADR / RID 2005



! **verifying compliance with transport limits before transportation**

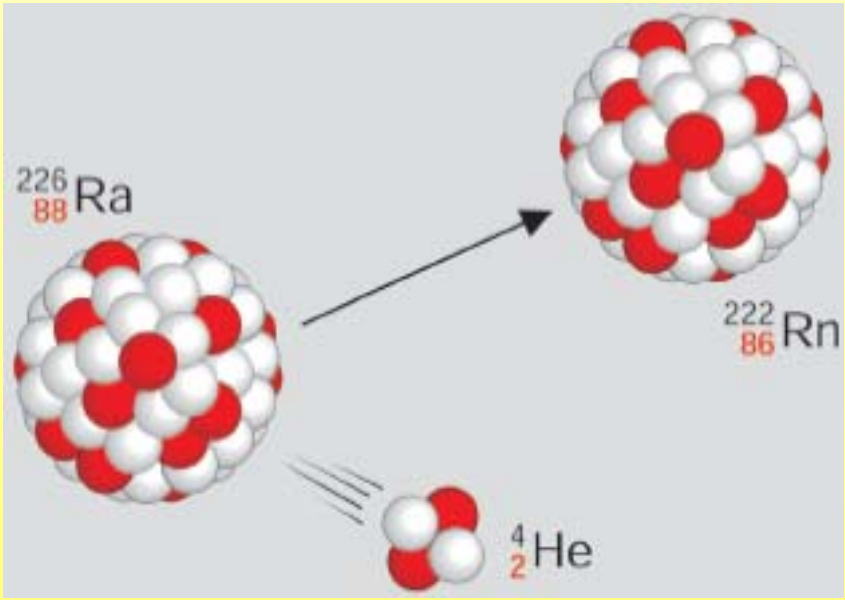
⇨ calculations with computer program e.g. Scale 4.4a

⇨ specific activity, decay heat, half-life etc. from databases e.g. Nuclides.net

✓ **approved transport package**

nuclide inventory

- known 116 elements
  approx. 2770 nuclides
- KADABRA 299 nuclides
  (HDB nuclide database)
- ADR / RID 2005 240 nuclides
  - limiting values for transport
  - key nuclides
    - (e.g. Co-60, Cs-137, Am-241…)
  - mother/daughter equilibrium
    - (e.g. U-232/Th-228, U-238/Th-234 & Pa-234m, Sr-90/I-90 & Y-90)



nuclide vector

- in practice 240 nuclides
  - minus half-life < 100 d
  - minus activities < 1E-15 Bq
- approx. 100 nuclides define a ‘nuclide vector’
- creating a virtual package with 14 drums based on KADABRA data
- conservative approach

  ⇨creating special nuclide vectors
  - highest loads for dose rate
  - criticality: U-233/-235, Pu-239/-241 (ADR/RID 2005)
  - highest loads for decay heat

transport package approval

- dose rate
  - at 1 m from surface < 2 mSv h^{-1}
  - ⇨computer program Micro-Shield 5.5
  - ⇨dose rate constants in 1 m distance from surface
- criticality
  - no chain reaction (criticality coefficient $k_{eff} < 1$)
  - ⇨computer program Scale 4.4a
  - ⇨Monte-Carlo simulation of the neutron flux
- heat
  - no temperature problem for the package
  - sun & decay heat
  - ⇨computer program Heating
  - ⇨finite element method

dose rate

⇨ 2 mSv·h^{-1} at 1 m from surface

⇨ calculations before packing

nuclide*		number of drums	total activity / Bq	proportion / %	dose rate constant (1 m) / Bq μSv^{-1}h^{-1}	theoretical max. activity / Bq / drum
Cs-137	β	32339	1.75E+13	58.32	7.19E+07	2.10E+04
Co-60	β	31964	1.39E+12	22.19	1,50E+07	1.67E+03
Cs-134	β	31344	4.75E+11	4.40	2,58E+07	5.68E+02
Rh-106	β	31425	3.26E+12	3.92	1.99E+08	3.90E+03
Sb-125	β	30905	1.14E+12	2.63	1.04E+08	1.37E+03
		KADABRA	KADABRA		Micro-Shield	

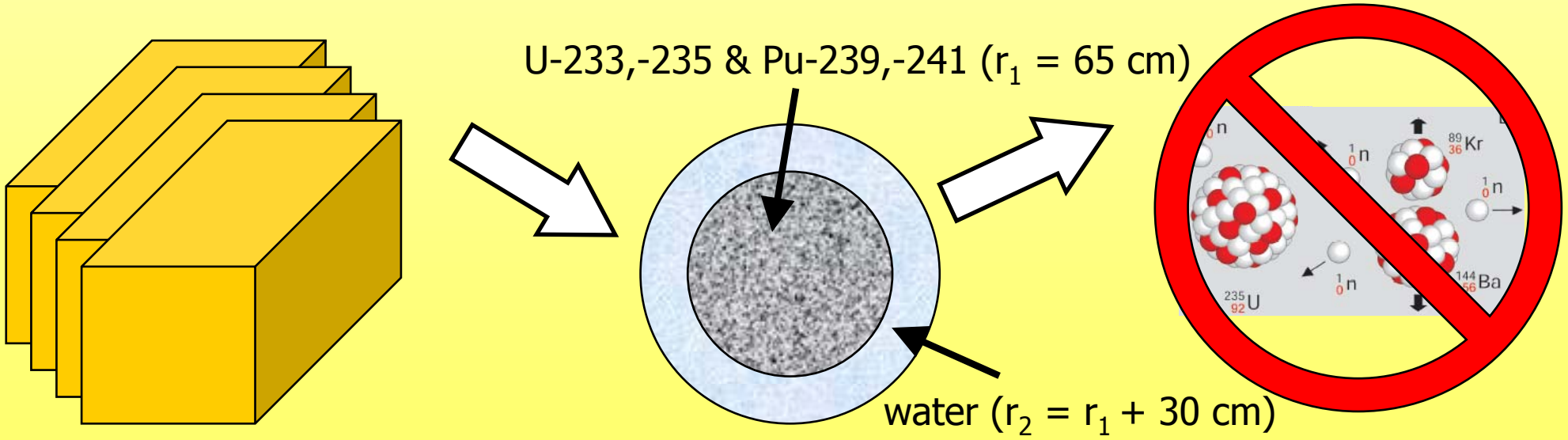
* excerpt from nuclide vector

maximum possible activity inventory in 1 drum

criticality

example: accident conditions

- load of 4 packages (ADR)
  - ⇨limited by KONRAD regulations up to 50 g/100 l of fissile material
  - ⇨concentrated in a sphere, no cement, no shielding material
  - ⇨surrounded by water as reflector material



⇨**no sustainable chain reaction ($k_{eff} < 1$)**

Scale 4.4a calculation

- input values Scale 4.4a

nuclide*		total activity / Bq	specific activity /Bq g^{-1}	total mass / g	proportion / %	mass fraction / g·(50 g)$^{-1}$
U-233	β	1.21E+07	3.56E+08	5.53E+02	0.004	0.002
U-235	β	2.82E+04	7.78E+04	5.76E+06	36.9	18.4
Pu-239	β	1.04E+13	4.54E+03	4.54E+03	0.03	0.015
Pu-241	β	9.18E+14	9.85E+06	9.85E+06	63.1	31.6
		KADABRA	Nuclides.net			for Scale 4.4a

* excerpt from nuclide vector

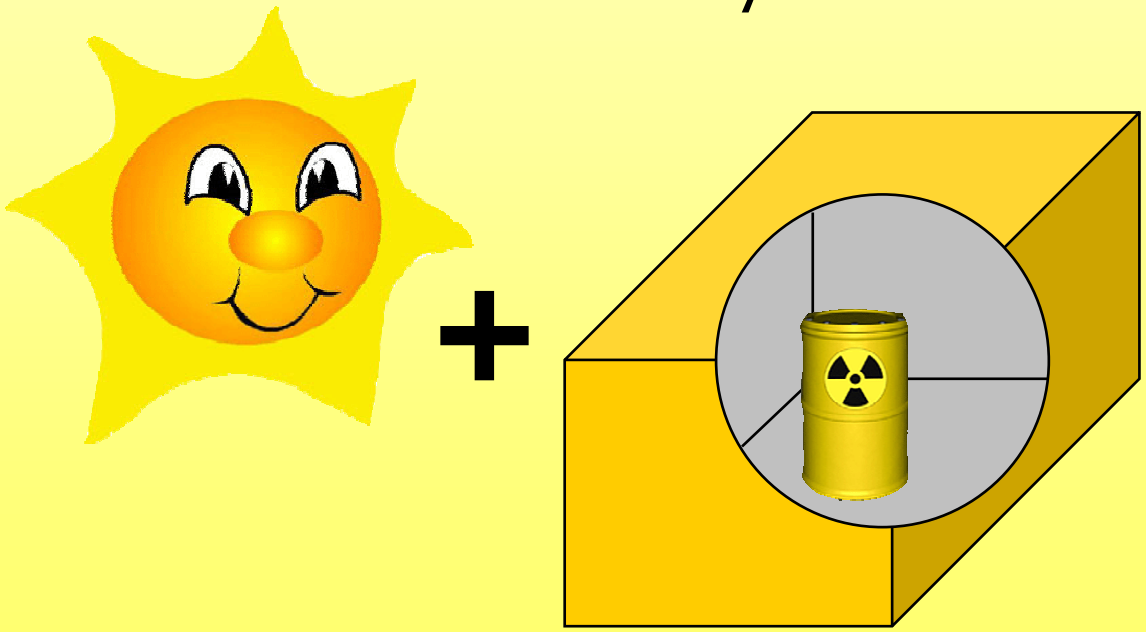
- assuming U and Pu as UO_2 and PuO_2 in the sphere

⇨ $k_{eff} < 0.60$ ⇨ no chain reaction

heat

transport conditions

- 1 drum in the center of the package contains all nuclide inventory (ADR)
  - ⇨ambient temperature 38 °C
  - ⇨12 h exposure to the sun & decay heat



⇨**no significant (dangerous) increase in temperature**

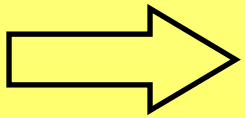
Heating calculation

- input values for Heating

nuclide*		total activity / Bq	specific activity / Bq g^{-1}	isotopic power / W g^{-1}	proportion / %	decay heat / W
Am-241	α	1.27E+07	1.27E+11	1.14E-01	77.3	167
Pu-238	α	2.82E+04	6.34E+11	5.67E-01	11.1	24
Pu-240	α	1.04E+13	8.40E+09	7.03E-03	4.2	9.09
Pu-239	α	1.04E+13	2.29E+09	1.93E-03	4.0	8.73
Y-90	β	9,18E+14	2.02E+16	3.01E+03	0.8	1.79
		KADABRA	Nuclides.net	Nuclides.net		210.61

* excerpt from nuclide vector

- heat generated
  - by sun: 9344 W
  - by decay: 211 W



- temperature
  - at the top 72 °C
  - in the center 60 °C

conclusion

- nuclide declaration is important
  - conservative assumptions
- different (virtual) nuclide inventories for each case
  - dose rate
  - criticality
  - decay heat
- reliable data source needed

⇨ input values for the computer programs
  - e.g. Micro-Shield, Scale, Heating

✓ approved transport package

acknowledgements

HDB, Karlsruhe, Germany:

- Luis Valencia
- Heike Merx
- Ralf Steiner

NFCC, Zürich, Switzerland:

- Bengt Tveiten

Thank you !